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A case study of solar photovoltaic power system at Sagardeep Island, India

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Abstract

The application of renewable energy in electric power system is growing fast. Photovoltaic and wind energy sources are being increasingly recognized as cost-effective generation sources for remote rural area isolated power system. This paper presents the performance analysis of solar photovoltaic (SPV) system installed at Sagardeep Island in West Bengal state of India. The technical and commercial parameters are used to carry out the performance analysis. The effect of the SPV installation on social life is also studied. SPV installations not only provide electricity to people but also raised their standard of living.

Keywords: Loss of load hours (LOLH); Prepaid energy card (PEC); Solar photovoltaic (SPV); Wind turbine generator (WTG); West Bengal Renewable Energy Development Agency (WBREDA)

Contents

1. Introduction

As per 2001 census data, only 43.5% of Indian rural households have access to electricity. Villages in remote areas are not connected by the electric grid because of high cost of installation of electric lines. It may not be possible to lay the line in some isolated areas. In India, there are about 94,000 un-electrified villages, out of which around 25,000 villages are

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Nomenclature

a, b	constants obtained for a particular location
a_1, b_1,	constant based on sunrise hour angle
$\bar{H}_d$	monthly average of the daily diffuse radiation on a horizontal surface at a location (kJ/(m^2 day))
$\bar{H}_g$	monthly average of the daily global radiation on a horizontal surface at a location (kJ/(m^2 day))
$\bar{H}_0$	monthly average of the daily extra terrestrial radiation which would fall on a horizontal surface at the location under consideration (kJ/(m^2 day))
$\bar{I}_b$	monthly average beam radiation (kJ/(m^2 h))
I_{bn}	beam radiation in the direction of rays (W/m^2)
$\bar{I}_d$	monthly average diffuse radiation (kJ/(m^2 h))
$\bar{I}_g$	monthly average of the hourly global radiation on a horizontal surface (kJ/(m^2 h))
I_g, I_b, I_d	hourly global, beam and diffuse radiation (W/m^2)
$\bar{I}_{sc}$	extra terrestrial radiation (W/m^2)
I_T	solar radiation falling on the tilted surface (W/m^2)
$\bar{I}_0$	monthly average of the hourly extra terrestrial radiation on a horizontal surface (kJ/(m^2 h))
n	day of the year
r_b, r_d, r_r	tilt factor of beam, diffuse and reflected radiation
$\bar{S}$	monthly average of the sunshine hours per day at location (h)
$\bar{S}_{max}$	monthly average of the maximum possible sunshine hours per day at the location (h)

Greek symbols

β	slope angle (°)
δ	declination angle (°)
ϕ	latitude angle (°)
γ	surface azimuth angle (°)
θ_z	angle of incidence on a horizontal surface
ω	hour angle (°)
ω_s	hour angle to sunrise (°)

located in remote geographically isolated areas where extension of existing electricity grid is not economically viable [1]. The National Electricity Policy 2005 aims at achieving a minimum consumption of one unit per household per day by year 2012. Indian Electricity Act 2003 provides the requisite framework for expediting electrification in rural areas. It permits operation of the stand-alone system in rural areas; independent of regulatory regime. It also provides the framework where the distribution of electricity in rural areas can be taken up by NGOs, Panchayati institution, etc. [2].

Presently the capital cost of photovoltaic system is about \$4000 kW^{-1}, while the cost of conventional power system such as oil, gas and coal is approximately four times lower. But the operating cost associated with these conventional plants is unacceptably high due to escalating fossil fuel costs. Further, there are difficulties in fuel delivery and equipment maintenance. Small isolated conventional diesel plants fulfill the demand of electricity in these areas. Considerable fuel savings can be achieved by integrating renewable sources such as wind and/or solar energy with existing diesel plants. Though photovoltaic (PV) is far from being economic in comparison to conventional fossil fuel for providing electricity, it is used in remote areas where it is uneconomical to extend the electric grid. However, the market for PV is also expanding rapidly due to reduced manufacturing cost of PV systems during the last decade [3]. A common method of using wind and solar energy in remote areas is to operate the wind turbine generator (WTG) and/or the PV unit in parallel with diesel generators in order to reduce the diesel consumption and thus save fuel. This mode of operation is particularly suitable for systems with relatively small renewable energy penetrations [4].

Many researchers have contributed papers on solar photovoltaic (SPV), wind and hybrid wind–SPV systems. Rahman and Chowdhury [5] presented number of photovoltaic performance analysis models and their impact on electric utility's load shape under supply side peak load management conditions for eastern and western parts of US and cost saving effect of battery bank.

Kellogg et al. [6] presented an application of a hybrid wind/SPV power generating system for utilization as a stand-alone or a network connected system. The optimum combination of wind and SPV generation coupled with battery storage for a stand-alone system was obtained for a hypothetical site in Montana.

Hiyama and Kitabayashi [7] presented an application of artificial neural network for the estimation of maximum power generation from the SPV module considering environmental factors such as irradiation, cell temperature and wind velocity.

Zahedi [8] presented an electrical model of a photovoltaic–battery system, which helps to understand the behaviour of a solar–battery system under various load and irradiance conditions. The complete electrical circuit of the entire hybrid system, the mathematical model and computational technique were presented.

Shrestha and Goel [9] discussed the issues in optimizing the use of isolated small PV power generation in remote areas and demonstrated the procedure to evaluate the different PV schemes considering the stochastic nature of the insolation and the load requirement.

Nehrir et al. [10] reported development of computer approach for evaluating general performance of stand-alone wind/PV with simple model for different components integrated and used to predict the behaviour based on available wind solar and load data.

Celik [11] presented yearly system performance of autonomous photovoltaic–wind hybrid energy systems with battery storage and simulated using the predetermined combinations. It was shown that the yearly system performance predicted from the 3 and 4-day synthetic data closely agreed with that obtained from the measured data, varying only slightly for different combinations.

Maghraby et al. [12] evaluated the design of the PV system using three probabilistic methods. One is considering fixed days

of battery back up and recharge and the other is based on loss of load probability (LOLP). The third is based on Markov Chain Modeling. LOLP distinctly shows reduction in number of panels and size of batteries while providing a detailed view of the system performance.

Kaldellis et al. [13] determined the optimum dimensions of an appropriate stand-alone photovoltaic system, able to guarantee the coverage of remote consumers energy demand located in typical Greek territories using long-term measurements. A detailed energy balance analysis of selected stand-alone photovoltaic system was done on an hourly basis.

Billinton and Karki [14] presented the simulation method that provides objective indicators, which help the planners to decide operating policies, and selection of energy types, sizes and mixes in capacity expansion when utilizing PV and wind in small isolated systems. Ehnberg and Bollen [15] presented the simulation results of global solar radiation based on cloud observations.

Markvart et al. [16] described the sizing procedure based on observed time series of solar radiation, which uses the geometrical construction as a superposition of contribution from individual climatic cycles of daily solar radiation.

Chakrabarti and Chakrabarti [17] examined socio-economic and environmental point of view, the feasibility of decentralized SPV system as a source of power compared to that from conventional sources in a remotely located island.

Bhattacharjee [18–20] explained how a renewable energy master plan and a series of projects with the involvement of local communities, and provide a sustainable and reliable source of power that can be achieved.

Moharil and Kulkarni [21] described the design of solar photovoltaic water pumping system by considering the effect of total dynamic head, azimuth angle and frictional loss in piping.

This paper presents the performance of SPV system at Sagardeep Island. This includes estimation of solar radiation at the island, estimation of power generated during different months. The minimum and maximum power generated values are obtained from historical data and their effect on demand is also studied. The loss of load hours is calculated considering the power generation and load requirement of different months. Further, the economics and social impact related to SPV system are discussed.

2. Site details

Sagar Island is located in the southwestern corner of the Ganges Delta, in West Bengal state of India. It is one of the largest of the hundreds of islands that make up the Sunderbans, a delicate ecosystem of tidal mangrove swamps and waterways that spread across the mouth of the Ganges. The name Sunderban has been derived from Sundari trees, which have peculiar pneumatophoric roots and are predominant here. Sunderban literally means ‘‘Beautiful Forest’’. It is an abode of famous Royal Bengal Tiger. The biosphere reserve still preserves the natural habitat of about 200 Royal Bengal tigers, which are strong swimmers and are bigger and richer in colour than other tigers elsewhere in the South Asia. The wildlife also includes spotted deer, wild boar, fishing cats, water monitors, olive ridley, sea turtles and large estuarine crocodiles. Sagardeep Island is a part of 24 Pargana district in West Bengal in India. There are 46 villages in Sagardeep Island, where river Hoogly falls onto the sea at Bay of Bengal. Sagar Island with an area of 465 km^2 (nearly 31 km $\times$ 15 km), out of which 50% of the land is under agriculture, 40% is non-cultivable and remaining 10% comprises of waterways, embankments, etc. The place is known for a large annual pilgrimage to Gangasagar, the main city of Sagar Island for a holy festival.

Fig. 1 shows the location of Sagardeep Island and the road to reach from Kolkata, a capital of state of West Bengal. It is 96 km away from Kolkata by road and further 6 km distance is to be covered by river route. Economy is developing fast as the people are hard working. They are engaged in agriculture, fishing trade, deep-freeze storage, betel vine, chilli cultivation, tourism, etc. To protect the natural habitat, environment and the biodiversity of the region, the Sunderban Biosphere Reserve was established in 1989 covering an area of 8630 km^2, including about 5366 km^2 of human habitat and forest. The remote villages and hamlets of the southern part of the Sunderban suffer from chronic shortage of energy due to non-availability of grid power. It is extremely difficult, to extend high-tension transmission lines to these areas as wide rivers and creeks separate them from the mainland and from each other at most of the places. It is highly cost prohibitive to draw transmission lines across very wide rivers and creeks.

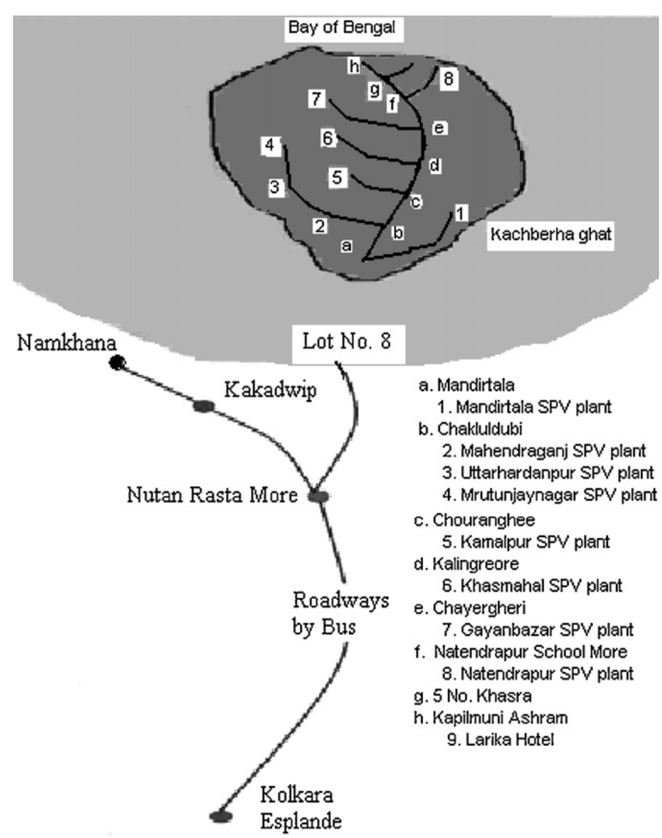

Fig. 1. Route map of Sagardeep Island and location of SPV installed villages at Sagardeep Island.

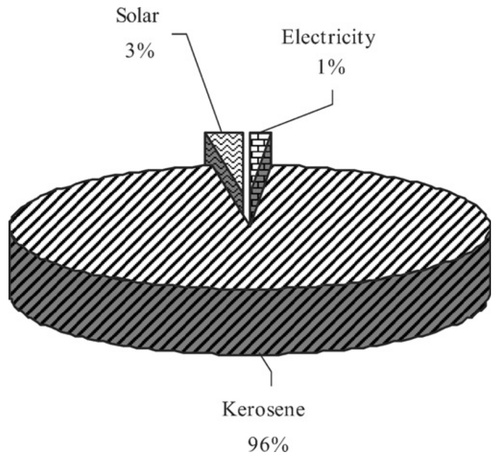

Fig. 2. Various sources used for lighting by households at Sagardeep Island.

It is a challenge, not only because of the difficulty in providing electricity access to the entire island but also because of the fragile ecology and environmental sensitivity of the islands. As the region has the characteristics of sensitive ecosystem, remoteness, inadequate infrastructure for transport sector, acute and distributed demand for electricity and dependency on petroleum products imported from main land, there is absence of diesel-based grid systems set up by West Bengal State Electricity Board. There exists little or no reliable access to communication systems, television, and health facilities, for want of electricity. Motorized as well as manually operated boats are the common means of transport in the region.

To supply the grid power to the island will be very expensive as it involves the laying and maintenance of very high-voltage cables across the channel. This high distribution cost is associated with high line loss, which increases with the distance from the grid point and with low capacity utilization due to the lack of adequate demand for power. The national average line loss is now 21% of the production whereas in the rural areas it is still higher. Generating power for the whole island from diesel would be possible in theory only. The cost is comparatively high due to its high operation and maintenance cost, short system life, high fuel cost and pollution. Till 1996 only a few diesel-generating sets were installed to provide power to the selected consumers only for few hours in the evening. The SPV plant requires huge capital cost. SPV system is considered to be the right choice for providing clean energy to these remote settlements in the form of distributed electricity supply system. The rapid upward shift in the cost of imported oil has increased the cost of generation of electricity significantly by conventional diesel plant. On the other hand the cost of SPV cells is declining over period of time as a result of R&D activities. Therefore, a time will come when the per unit energy cost from the SPV plant would be comparable with that of the centralised power generating system at all levels in the rural electrification programme.

Fig. 2 shows the various sources used for lighting by various households in Sagardeep Island as per 2001 Census. The consumers used kerosene for lighting as the main energy source. Firewood is fuel for cooking. There were number of battery operated radio and musical systems prior to the extension of electric connection. Table 1 shows the SPV installation details in Sagardeep Island.

3. Estimation details

3.1. Solar radiation estimation

Solar flux striking a collector will be a combination of direct beam radiation, scattered or diffused radiation and reflected radiation. Since measurements of solar radiation are often not available, attempts have been made by many investigators to establish relationships linking the values of radiation (global or diffuse) with meteorological parameters like number of sunshine hours, cloud cover and precipitation. These equations for solar radiation at a site can be estimated if the latitude, longitude and altitude of location is known [22]. The related

Table 1
Installation details of SPV system at Sagardeep Island [19,20]

Sr. no.	Name	Month and year	Capacity (kWp)	Module cost (Rs. in lacs)	Cost per W (Rs.)
1	Kamalpur	February 1996	25	46.17	174.25
2	Mrityunjaynagar	October 1998	25	46.31	185.24
3	Khasmahal	May 1999	25	43.17	172.6
4	Gayenbazar	May 1999	25	43.17	172.6
5	Mahendra	August 1999	25	43.17	172.6
6	Natendrapur	August 2000	25	33.75	135.5
7	Haradhanpur	November 2000	25	33.75	135.5
8	Mandirtala	December 2000	25	33.75	135.5
9	Bollara	March 2003	110	[a]	[a]
10	Bondadna	April 2003	55	[a]	[a]
11	Parthapartim	March 2004	110	[a]	[a]
12	Indrapur	November 2004	110	[a]	[a]
13	Rakhalpur	June 2005	110	[a]	[a]
14	Koyalpara	October 2005	110	[a]	[a]
15	Dandpur	January 2006	55	[a]	[a]
16	Tushkahali	March 2006	55	[a]	[a]
17	Pathankhali	March 2006	55	[a]	[a]

[a] Cost not available.

equations are given below

$$\delta = 23.45\left(\sin\left(\frac{360}{365}(284+n)\right)\right) \tag{1}$$

$$\begin{aligned}\theta &= \sin\phi(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) \\ &\quad + \cos\phi(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) \\ &\quad + \cos\delta\sin\gamma\sin\omega\sin\beta\end{aligned} \tag{2}$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \tag{3}$$

$$\bar{H}_g = \bar{H}_0\left(a + b\frac{\bar{S}}{\bar{S}_{max}}\right) \tag{4}$$

$$K_T = \frac{\bar{H}_g}{\bar{H}_0} \tag{5}$$

$$\bar{H}_d = \bar{H}_g(1.390 - 4.027K_T + 5.531K_T^2 - 3.108K_T^3) \tag{6}$$

$$P = \begin{cases} -0.0622(\text{rad})^2 + 36.5073(\text{rad}) + 351.2987, & 0\,\text{W/m}^2 < \text{rad} < 190\,\text{W/m}^2 \\ (0.0022(\text{rad}) + 4.8821)\times 10^3, & 190\,\text{W/m}^2 < \text{rad} < 1000\,\text{W/m}^2 \end{cases} \tag{13}$$

$$I'_{sc} = I_{sc}\left\{1 + 0.033\cos\left(\frac{360}{365}n\right)\right\} \tag{7}$$

$$\bar{I}_o = I'_{sc}(\sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega) \tag{8}$$

$$\bar{I}_g = \bar{I}_0 K_T(a_1 + b_1\cos\omega) \tag{9}$$

$$\bar{I}_d = \bar{I}_0 K_T(a_2 + b_2\cos\omega) \tag{10}$$

$$I_g = I_b + I_d = I_{bn}\cos\theta_z + I_d \tag{11}$$

The flux falling on the tilted surface at any instant is given by

$$I_T = I_b r_b + I_d r_b + (I_b + I_d) r_r \tag{12}$$

3.2. SPV panel power estimation

Generally the radiation intensities in adverse weather are lower than those in normal weather during the daytime. The PV systems in adverse weather generate lower power than those in normal weather and cannot supply sufficient electricity to the load points.

A PV generation considering the three-state model is represented by the radiation intensity and the failure rate as shown in Fig. 3.

In Fig. 3, λ and μ are the failure rate and repair rate of PV system. Up state represents the radiation larger than 190 W/m^2 and no outage of PV system. Derated state represents radiation less than 190 W/m^2 and no outage of PV system. Down state represents outage of PV system or radiation intensity when it falls to zero.

The electricity generated by PV panel is variable and depends on incident solar radiation and ambient temperature.

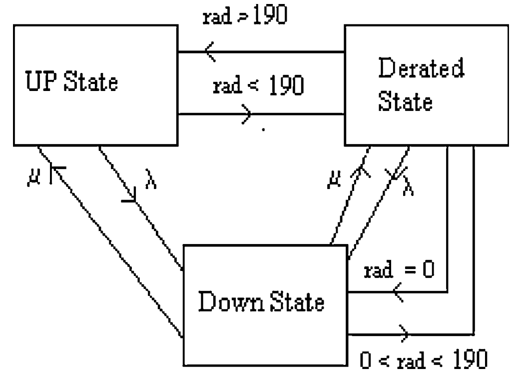

Fig. 3. Three state model of PV system.

For lower radiation the power output is linear to radiation value. After a knee point further increase in radiation produce relatively smaller increase in the power as shown in Fig. 4.

If the radiation at the site is known then the power output can be obtained by

4. Performance of SPV system at Sagardeep Island

4.1. Prediction of solar radiation

Sagardeep Island is located at latitude 22.65°N and at longitude 88.45°E. A MATLAB program is developed to predict the solar radiation at the site using Eqs. (1)–(12). Fig. 5 shows the (i) predicted values and (ii) 5 years monthly radiation data from 1998 to 2002 made available by India Meteorological Department, Pune. It can be observed that the predicted values and observed values match with one another.

4.2. Working of SPV system at Sagardeep Island

A SPV system installed at Sagardeep Island is taken for case study. It has a rated capacity of 25 kWp. West Bengal

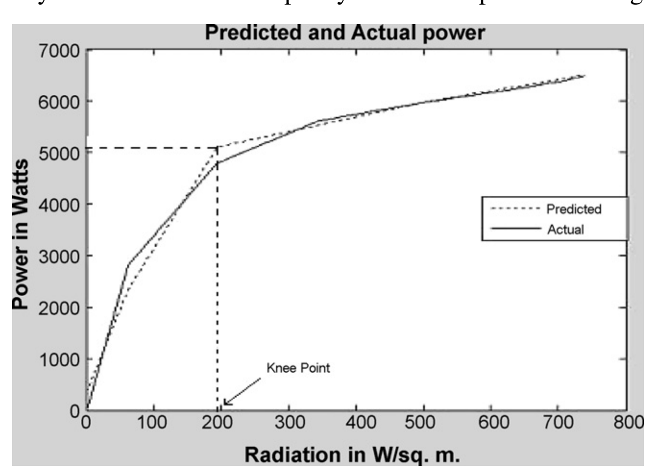

Fig. 4. Predicted and actual power of SPV installed at Sagardeep Island.

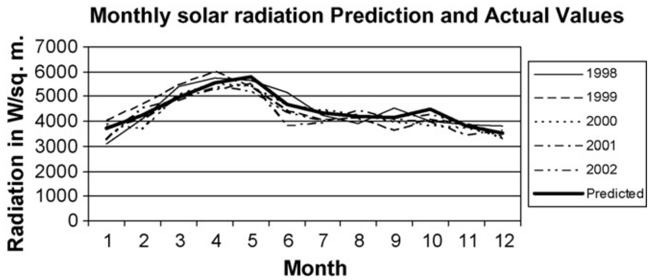

Fig. 5. Predicted and actual radiation at Sagardeep Island site.

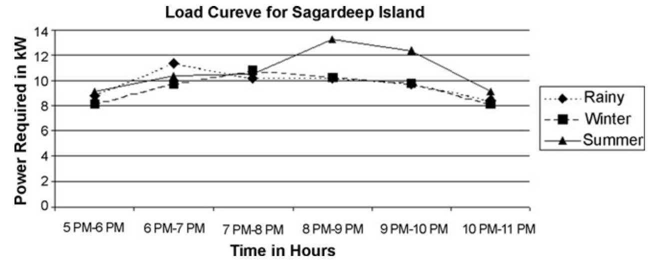

Fig. 7. Seasonal variation in load at Sagardeep Island.

Renewable Energy Development Agency (WBREDA), is the state level organization planning and promoting the use of renewable energy technologies (RET). In order to satisfy the growing aspirations of the consumers, and to serve the population in a better manner, WBREDA and Ministry of New and Renewable Energy (MNRE) have been promoting the installation of decentralized SPV power plants, which supply ac electricity to the village for a fixed duration.

Fig. 6, shows that the dc power generated by an array and stored in two lead acid battery banks (each of rating 2 V 800 Ah) during daytime and discharged during night time from 6 p.m. till the charge of the battery bank reaches to 20% of its rated value or midnight whichever is earlier. Additional power if available may be supplied in the morning hours from 4 to 6 a.m. DC power is converted to ac power through inverters (3× 15 kV A) and is connected to the consumer load through feeders (230 V, 50 Hz ac supply). The arrangement has three feeders, one feeder for plant and other two are for consumer loads. The system implements protective schemes including air circuit breaker (ACB) and minimum oil circuit breaker (MOCB).

The concept is popularized as electrification-based planning instead of device-based planning, and provision of electricity instead of light alone. These power plants are used for village electrification as well as for providing electricity to rural hospital.

4.3. Technical performance of SPV at Sagardeep Island

Fig. 7 gives the seasonal load variation at Sagardeep Island. It is observed that during the summer season power requirement is high because both lighting and fan load is increased. During the winter the peak requirement is during 6–7 p.m. slot and load gradually reduces, as the day length is small. During summer season the day length is more and the peak occurs during 8–9 p.m. slot. During rainy season only lighting load is required to be supplied.

Fig. 8 shows the average power output of one of the inverter throughout the year. Power is supplied till 12 midnight in the summer months (March–May). During rainy season because of cloud cover it is not possible to supply power for all 5 h as per schedule. In rainy season power is supplied only for 4 h.

From 5:00 to 6:00 p.m. less power is required during summer as compared to winter and rainy season. Maximum power is supplied in the month of May and minimum is supplied during July.

Fig. 9 represents the power generation minimum, maximum and average value. It is observed that during summer season when sky is clear on maximum days the minimum output is above average value. There is no much difference between minimum and average values. During monsoon months the power available is much lower as compared to other months. In

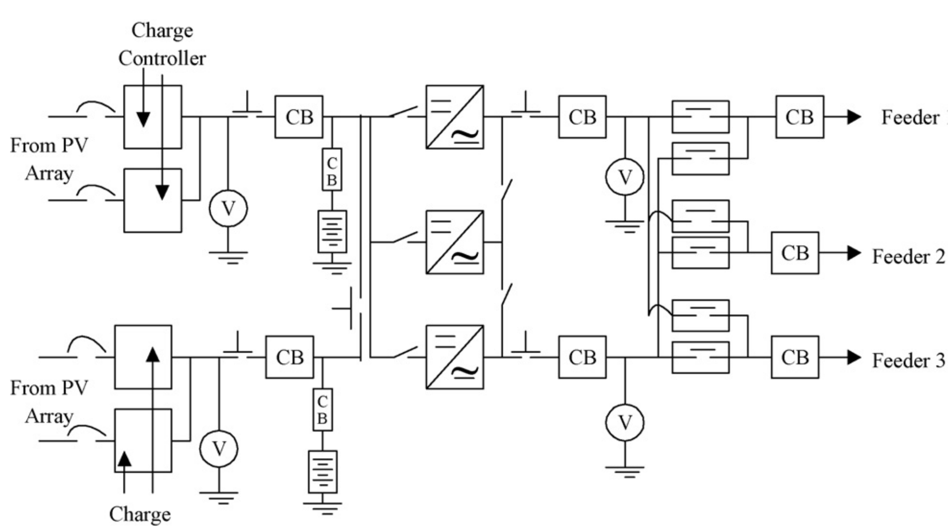

Fig. 6. Electrical connections of SPV array, battery, inverter, distribution grid at Sagardeep Island.

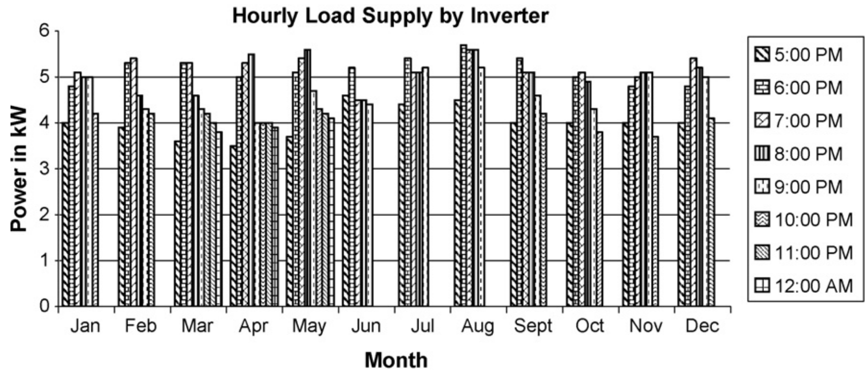

Fig. 8. Supply of inverter power at Sagardeep Island on hourly basis.

the month of February and October there is large variation between minimum and maximum values as compared to other months because the cloud cover is frequent during these 2 months. The power generation during the winter is fair than that in rainy season but lower as compared to summer months because of variation in declination angle during the winter season.

Fig. 10 shows the loss of load hours during different months. It is observed that highest loss of load hours is during rainy season. This is mainly because of non-availability of solar radiation. During summer season the loss of load hours is very less. In the month of May the loss of load hours is more as compared to other 2 months because of un-seasonal rains. During winter season negative declination angle (which indicates the sun is in southern hemisphere) is the cause for loss of load hours.

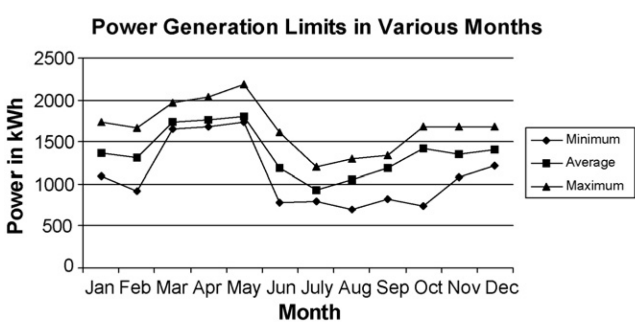

Fig. 9. Power generation limits in various months.

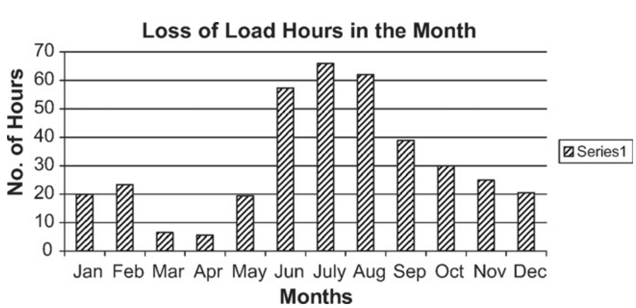

Fig. 10. Loss of load hours over the year.

5. Economics of SPV at Sagardeep Island

The plant with a 25 kWp-installed capacity provides electricity to households within 4.5–5 km radius through low-tension (LT) distribution line. On an average, every plant has 100 consumers. Consumers are divided into two categories: domestic and commercial. Electricity charges are based on a service connection cum fixed initial security deposit that is in the range of Rs. 1000–1500 and payment of Rs. 120 per month for 100 W connected load. For shops charges are fixed depending on load demand. Each consumer is expected to pay initial charges for getting the connection and cost for internal wiring, etc. These plants are managed by rural cooperatives, and the revenue collection method is through the account of the cooperative society in the Rural Development Bank. Number of people having income less than Rs. 2500 varies between 30 and 40%, 40 and 50% being those whose income is between Rs. 2500 and 5000 and the rest are having income above Rs. 5000 per month. The average family members are six in number. Number of school going children in a family is in the range of two to four. There are two types of consumers, three point and five point. Three-point consumers have two CFL points and one point for TV or fan. Five-point consumers have three CFL, one TV and one fan point. Grid system helps the power supplier to charge users for the power consumed, and thereby recoup at least some of the costs. The societies are responsible for the selection of consumers, choosing routes for the distribution lines, and the setting of the tariff in consultation with WBREDA. They are also responsible for the collection of payments from consumers, passing them onto WBREDA, and dealing with recovery problems. WBREDA supports the co-ops with advice on administrative and financial matters, and provides technical input through junior engineer who is permanently stationed on the island. The project is funded by a combination of grants, loans, and revenue. Government of India: 50% (grant), State government: 20% (grant), Other sources: 30% (includes revenue from consumers and loans). At present, the revenue collected from consumers covers 100% of the operational costs of the power plant and about 20% of the capital cost.

The performance of cooperative societies can be judged from realization of revenue. Revenue to the extent of above

95% is collected by these societies. Smart cards are being introduced for prepaid services, and also an automatic tripping device to prevent consumer from drawing excessive power than permissible limit.

An average consumer in the Sagardeep uses 12 l of kerosene per month, which costs around Rs. 120 when kerosene is supplied by Public Distribution system (PDS). But the PDS supply cannot fulfill the complete requirements. The consumers spend around Rs. 180 for kerosene. The consumer achieves saving in cost with the use of SPV and CFL.

5.1. Prepaid energy meter

Unfortunately the flat rate system is open to abuse. Only very expensive load limiters can limit the load on a system precisely, and users have found that they can ‘fool’ the Sagar systems by drawing more electricity than they are paying for. WBREDA started to install prepaid energy meters to ensure that consumers actually pay for what they use. Controlling this ‘loss’ of power will mean that the grids can supply electricity to more consumers and so allow project revenue to increase.

The Ashden Award for sustainable energy was conferred upon Mr. S.P. Gon Chowdhury, Director General of WBREDA. The award money has been used to start the process of installing prepaid energy meters in the houses of 125 families. It is also being used to provide grid connections for new consumers and to install solar streetlights in new parts of the island.

This embedded-chip based, smart card operated, prepaid energy meter has revolutionised the way electricity revenue is collected in isolated pockets and far-flung areas. First it has resolved the problems associated with billing consumers living in isolated areas. These include deployment of manpower for taking meter readings and delivering the bills to consumers in time. Second, the technology can be transferred to entrepreneurs interested in manufacturing such smart card operated energy meters. And third, with such meters in operation, one can do away with fears of power theft. For WBREDA, it means healthier cash flow management, as money would flow into its coffers ahead of supply.

It took WBREDA and Central Mechanical Engineering Research Institute (CMERI) more than 8 months to develop the smart card operated energy meter, which will be marketed under the Solaris brand name. Based on state-of-the-art, real-time embedded technology, the Solaris prepaid energy card is compact and can function even under harsh conditions and saline environments. Fig. 11 shows the prepaid energy meter card. The consumer has to simply take the smart card out of the meter whenever it is not in use. Inserting the prepaid Solaris energy card can activate the energy meter. The consumer can then use electricity for the card value. After the initial amount is exhausted the consumer can recharge the card by making fresh payments. In fact, the energy meter will alert the consumer when 75% of the prepaid amount has been exhausted. By recharging the card, the consumer can avoid automatic disconnection. The price of each prepaid energy meter has been pegged between Rs. 1500 and 2000 [23].

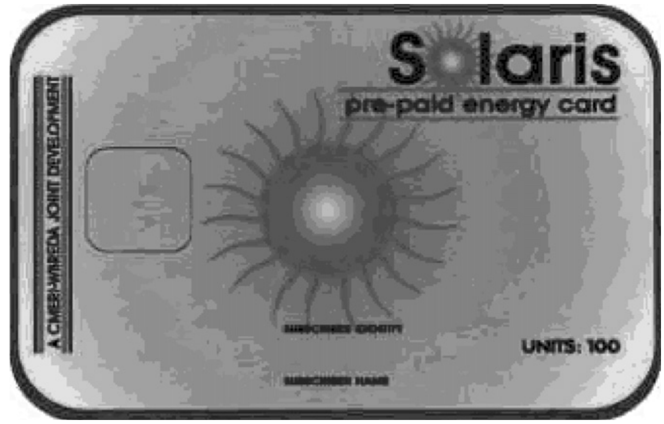

Fig. 11. Prepaid energy meter card used at Sagardeep Island.

6. Social impact of SPV

Around 2500 families are now enjoying electricity from SPV. The power supply at night has helped society in at least four ways. It has helped (i) the students to continue their study at night, (ii) the shopkeepers, cultivators of betel leaf to continue their work at night (iii) the people to avail themselves of the entertainment facilities and (iv) the women to do the household work. The supply of solar power has also helped, though on small scale to run the video hall, battery-charging center, etc. Streetlights make the island safer at night. Two hospitals on the island now have a 24-h supply of energy. One has its own solar power plant, while the other is connected to a mini-grid, with diesel generators providing power during those hours when the grid is switched off. The mini-grid SPV system has several advantages over the individual SPV system. It delivers better quality power – three-phase ac power – that can be used for operating small electrical machinery for village industries. Distribution is via a mini-grid. It also allows for ‘diversity’, meaning that many premises can be connected to the same system, given the fact that they will never all be using power for their loads exactly at the same time. The project has employed an innovative way of integrating water pumps into the mini-grid systems, and is used to bring clean, safe drinking water to the surface from deep aquifers during the daytime when the supply to grid is switched off. Despite the higher cost, the people irrespective of their income level are demanding more power now for entertainment, comfort and development work. 46% of the households have expressed their willingness to pay even more than what is being charged at present for getting power.

7. Conclusions

Well-established technology, simple operation and maintenance, downward trend of cost, optimum resource availability in remote and island areas, environmental sustainability, good

management systems, etc., are indications of large scale installations of solar power plants in near future at Sagardeep Island. With the demand not exceeding 20–25 kW at a load factor less than 30% and where conventional power cannot reach as techno-economically viable proposition, SPV system will offer a competitive option there. Acceptability of system by the people both on commercial operation and quality of power supply are guiding principles. The fee for service payment model is effective, and there is less abuse by consumers when meters are used instead of a flat fee per connection. Here consumers are benefited, viewed in the context that the electricity is at their disposal, which is the important ingredient to raise their standard of living.

It is hoped higher size units to cater for longer period of supply will come up soon for healthy growth of the society to cover domestic and commercial consumers, small agriculturist and tiny industries in remote areas. It is also hoped that the use of hybrid system such as PV–wind system will increase reliability of power supply in future.

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Appendix A

Details of SPV plant located at Mahendraganj plant.

Capacity	26 kWp (357 × 75 Wp modules)
Module details	120 cm × 57 cm size; 36 cells; V_{oc} = 21.7 V; I_{sc} = 4.8 A; V_m = 17 V; I_m = 4.4 A
Battery bank	2 Nos.
Battery details	60 cells in series; V_{nom} = 2 V; V_{max} = 2.33 V; cell current = 20 A; specific gravity = 1200; capacity 800 Ah
Charge controller	120 V dc, 100 A
Inverter voltage	Input: 120 V dc and output: 3 phase 400 V ac
No. of inverters with capacity	3 inverters of 15 kVA
No. of connections	120
No. of feeders	3 No.
Initial charge for service connection	Rs. 1000 per connection
Total cost of project	Rs. 10.6 million

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